International Journal of Engineering Education (IJEE)
e-ISSN : 2540-9808

Development of a Game-Based e-Learning System with Augmented Reality for Improving Students' Learning Performance

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Abstract - *Currently, the school children usually spend a lot of time on the games in their recreational activities and some of them are even addicted to the games. Compared with other extracurricular activities, the e-Learning system reflects the fact that school children are very interested in the games. As a result, educators have lately craved to develop effective teaching activities that allow the school children to learn some subjects and to play the games simultaneously. Therefore, this study is based on an e-Learning system which combines the serious game by Unity3D Game Engine with augmented reality (AR). Students are able to acquire their knowledge and to foster logical skills via this game-based e-Learning system. According to its efficacy and utilities, this study has assessed and compared the game-based e-Learning system with the traditional learning and other e-Learning systems. The experimental results have indicated that the proposed game-based e-Learning system with the excellent average value, 82.10, can outperform other existing systems.*

Keywords *–Magnetic field, Artificial intelligence, Game-based e-Learning, Augmented reality, Performance assessment.*

Submission: June 4, 2019 Correction: October 5, 2020 Accepted: January 10, 2020

Doi: http://dx.doi.org/10.14710/ijee.2.1.1-10

[How to cite this article: Yang, S.-H., Wang, Y.-Y., Lai, A.-F., Lin, Y.-N., Chiou, G.-J., Chen, M.-K., Shen, V. R. L., Hsiung, C.-Y. (2020). Development of a Game Based e-Learning System with Augmented Reality for Improving Students' Learning Performance. *International Journal of Engineering Education, 2*(1), 1-10. doi: http://dx.doi.org/10.14710/ijee.2.1.1-10]

1. Introduction

The Ministry of Economic Affairs proposed a project entitled "2014 Project on Applications in Digital Industry and Promotion of Sound Environment". In the survey of the project, school children's behaviors for the online games indicated that 70 percent of them considered the games as their first choice. Their recreational activities are highly related to the games [1]. Thus, since some school children are bad at self-control, they would spend a lot of time on the games more than they should.

This study aims to set up the serious games that assist in thee-Learning system so that school children are allowed to retain knowledge by playing games. Not only can they learn via textbooks, but also they are able to grasp it by recreational activities, which reflect the concept of game-based learning; in other words, learning by playing [2]. A subject on science and technology concentrates on learning how to observe instances around the environment. But some phenomena in the natural science subject can't be illustrated in the textbooks, such as the flow of water and the effects of wind on the environment. This kind of problem motivates us to develop the game-based e-Learning system.

Furthermore, using augmented reality (AR) is more different from the traditional e-Learning system. It can facilitate the interaction between children and natural science subjects. So, school children are capable of seizing and visualizing the complex concepts of space and abstract principles [3]. This learning technology has become the primary concern for game developers and creators.

Currently, in many e-Learning systems, some distinguished platforms, such as Moodle, Sakai and D2L, are categorized as the open sources. According to SCORM (Sharable Content Object Reference Model)[4], teaching materials can be input and output on these platforms. However, these platforms are probably too complicated to be operated by school children. But comparing to some other games, school children are usually good at playing the board games with high complexity of the game rules [5].

The remainder of the paper is organized as follows. In Section 2, we present a literature review of the game-based e-Learning system with AR. Also, the traditional assessment and performance assessment are discussed. In Section 3, we propose the game-based e-Learning system with augmented reality. The experimental results and analysis results are discussed in Section 4. Finally, the conclusion is remarked in Section 5.

2. Literature Review

In this Section, we first describe the background and development of game-based learning and serious games. Then, some basic definitions regarding performance assessment and application of augmented reality (AR) to e-Learning are presented.

2.1 Game-Based Learning and Serious Game

As the rapid development of computer technology, the combination of traditional learning with e-Learning has become educators and scholars' main concerns. For the game-based learning, learners are efficient and capable of acquiring knowledge by playing [2]. For the serious games, learners can respond to their simulations [6]. Meanwhile, these pioneering learning platforms have been applied to corporations and army like a virtual battle space [7].

Just like Dewey's theory, school children can perform learning by playing and learning by doing [8]. The real importance of good computers with video games is that they allow people to recreate themselves in the new world and to deeply learn some knowledge at the same time. This idea was proposed by Gee in 2003[9]. Nowadays, the e-Learning system can be used to reduce and to overcome the difficulties in classrooms, including lecture hours, student's different learning situations, course discussion, and other learning assessments. So, the game-based learning was viewed as a new teaching trend in the e-Learning pedagogy.

However, the game design theory was proposed by Merill, Hammons, and Vincent in 1995. There are four guidelines, namely, *nonviolence*, *entertainment*, *restricted players*, and *competitive* or *challenging* [10]. So, players in the game have different levels of tasks on the requirements or restrictions for solving problems and making some checkpoints. In the recent years, the game-based e-Learning development has gradually produced simple teaching professional courses such as coding concepts, as shown in Figure 1.

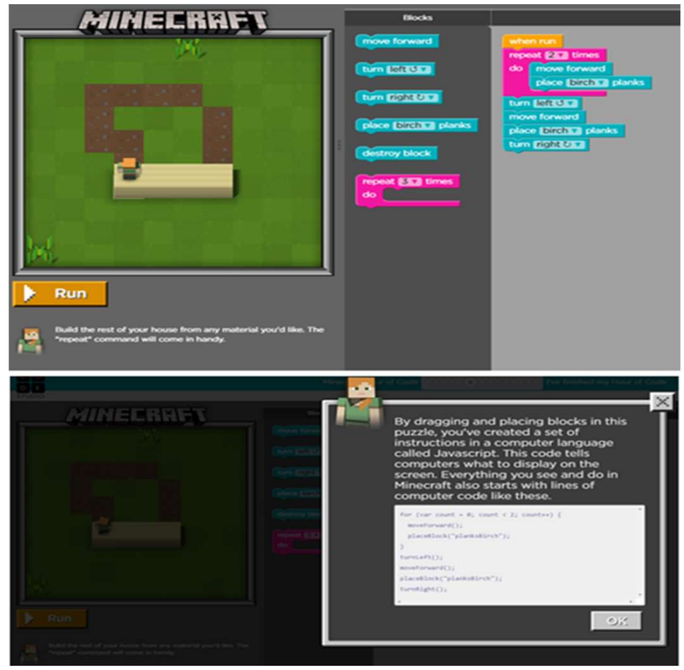

Figure 1. Gamed-Based learning for coding courses by Code.org [11].

2.2 Performance Assessment

The main purpose of assessment allows teachers to evaluate students' performance and to adjust their teaching methods. However, due to the limited time and space in the traditional teaching method, most of the schools are used to testing students on papers. So, teachers intend to "teach to test" and spoon-feed their students. It is prone to questioning and narrowing down their teaching materials, and the course just focuses on teaching students how to be easily overlooked.

Performance assessment is defined as the procedure in which a teacher uses work assignments or tasks to obtain information about how well a student has learned [12]. After the assessment of the actual course contents, for a student completing his/her performance by scores, it has five categories, namely, paper-and-pencil performance, identification test, structured performance test, simulated performance, and work samples, as shown in Table 1. Thus, the game-based e-Learning system belongs to the fourth category.

Table 1. Classification of performance assessment [13].

Category	Example
1. Paper-and-Pencil Performance	Complete a test report.
2. Identification Test	Identify changes in scientific inquiry activity.
3. Structured Performance Test	Follow the instructions to experiment.
4. Simulated Performance	Use the computer simulation system and get the simulation experiments.
5. Work Samples	Experiments conducted in the laboratory.

Also, for the knowledge assessment, concept mapping is a more flexible one, which is usually applied to make the connections with connecting lines, i.e., concept and conjunctions, which are stratified [14, 15]. Many scholars view the concept mapping as a good efficient learning tool by which educators can assess students' performance. It is confirmed that the cognitive ideas learned by students are correct, and the relationship among concepts is understood well, as shown in Figure 2.

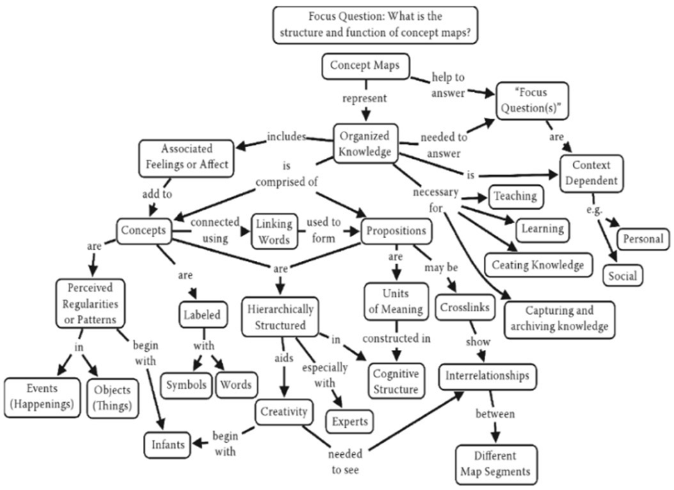

Figure 2. Concept mapping and features [15].

2.3 Augmented Reality

Augmented reality (AR) is adopted to calculate the real-time position and angle in camera image by using the corresponding image technology. The goal of this technology on the screen is to set the virtual world and to make interactions with the real world. There are two common definitions. First was proposed by Azuma in 1997 [16]. In his viewpoints, AR includes three parts, namely, virtual objects and reality, real-time interaction, and three-dimension. Second was proposed by Milgram and Kishino in 1994 [17]. They are real and virtual environment, respectively, as both ends of the continuum. In the middle of it, it is called "mixed reality". The portion close to the real environment is called AR, as shown in Figure 3.

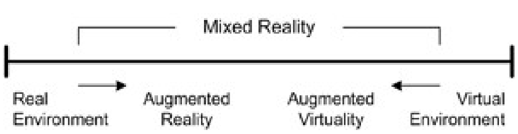

Figure 3. Milgram's reality-virtuality continuum [17].

The main feature is to simulate the processes of cameras feeding images into computers. It overlaps the images including the combination of the reality in space with the instant interactions registered in 3-D, as shown in Figure 4.

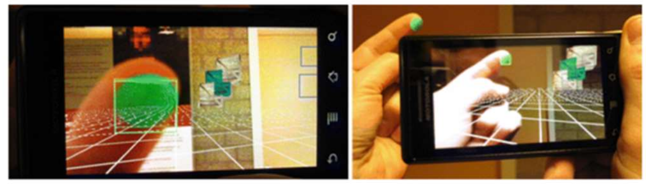

Figure 4. Application of AR to mobile devices [18].

Billinghurst and Duenser proposed five attributes in the combination of AR withe-Learning [19], namely, the concepts of space and time, the relationship between reality and virtuality, the interaction for sensors, the experience of 3D visualization, and the collaboration, as shown in Figure 5. By illustrating the space which the virtual magnetic field influences, students can see the magnetic field lines produced by movable magnets in the diverse positions. Students can acquire more knowledge by discussing and collaborating with each other when they see the lines generated by the magnetic field immediately [19, 20].

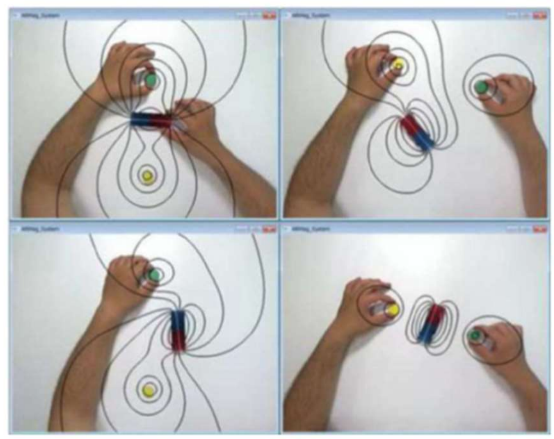

Figure 5. Learning virtual magnetic field through AR [20].

2.4 Characterization of catalysts and products

The bulk structure of natural zeolite was confirmed by the X-Ray Diffraction (XRD) analysis (Rigaku Corp., Japan) using the Copper K alpha radiation. The composition of natural zeolite was determined by the X-ray Fluorescence (XRF) analyser. Nitrogen adsorption-desorption measurements were conducted at 77 K on a Belsorp-mini II (Bel Japan). The BET specific surface area (S_{BET}) was calculated from the adsorption data in the relative pressure. The Scanning Electron Microscope (SEM: JSM-5310LV Microanalyzer, JEOL Co.) was employed to determine the surface morphology of catalysts. The fraction of liquid products were analysed by using a gas chromatography-mass spectrometry (GC-MS, QP2010S Shimadzu). The gaseous product composition was measured by a gas chromatograph equipped with a thermal conductivity detector (GC-TCD, Agilent Technologies Inc. USA).

3. The Proposed System

The scales of e-Learning environmental assessment were proposed by Dougiamas and Taylor [25]. According to the e-Learning system assessment scales, the teaching materials concentrate on relevance, interactivity, and reflection. So, there are four steps to set up the structure of teaching and learning materials. First, build up the teaching contents of the subject on science and technology based on the curriculum guidelines by the Ministry of Education, which should comply with the standards of SCORM. Second, make quizzes before class and after class. Third, revise the architecture of a game-based e-Learning system, which includes the AR with serious games. Fourth, evaluate and assess this system in order to figure out the learning performance and the parts of course content needed to be revised [21-24].

3.1 Learning Management System

SCORM [4] is actually an instructional design, adaptive learning system, and many other educational concepts with computer software technology, especially, the distributed service technology closely integrated with product data modeling. It provides a standard specification for digital materials on the LMS (Learning Management System) platform. To formulate the teaching materials for e-Learning, this platform is complied with the standards of SCORM so that teachers can output the teaching materials to other platforms. The materials' structure can lead to SCO (Shareable Content Object) [26]. Part *a* denotes its branch item. Part *b* denotes its link to the SCO. In part *c*, each SCO has many resources. Part *d* denotes simple sequencing [27, 28]. However, SCOs still need to be conformed with LMS. So, learners are able to follow the instructions to utilize the course contents in SCO.

3.2 Game-Based e-Learning System

This system has been developed via Unity3D Game Engine, compiled by many computer languages [29], such as JavaScript, C#, and Boo, which can be converted to and be switched from each other. The SCO needs LMS to be operated. So, this system is based on Moodle, which shares the Unity3D with the database. After implementation, the teaching materials presented by AR and the 3D objects can be displayed. Then, users can see the game scene based on serious games [30]. Developers can get a feedback from learners on LMS after observing the learner's behavior by playing, as shown in Figure 6.

3.2.1 Augmented Reality and Serious Game Scenes

Our AR scene uses the image reading engine in Vuforia SDK [31]. Developers' job is to develop resources for the Unity3D and contents of AR. Vuforia works for Vuforia Engine and Target Management System. In the target management of AR, it also supports Target Database on cloud. Because of the physical computing formula of Unity3D, we design an AR target, and utilize Terrain (Unity3D objects) inside the engine to compute the outdoor status in order to simulate the subject on science and technology, such as "air flow". After detecting the images, Vuforia SDK can catch the data objects from Unity3D and LMS, as shown in Figure 7.

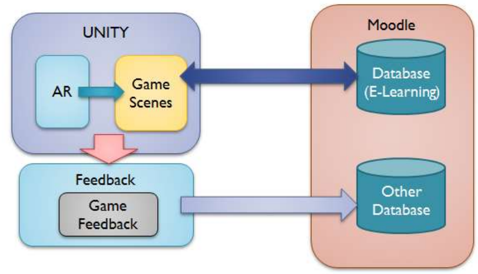

Figure 6. Game-Based e-Learning system architecture.

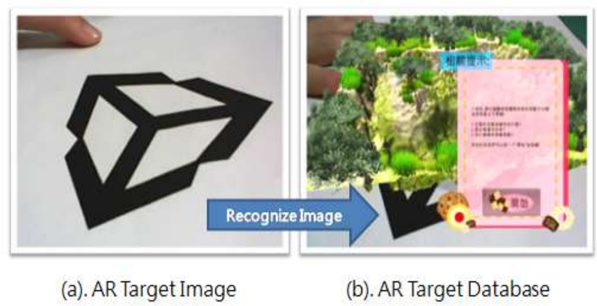

Figure 7. Target image and database objects in AR scene.

For the serious game scenes, Wouters proposed four categories of learning outcomes, namely, *cognition*, *motor skills*, *affection*, and *communication*. Cognition comes from the knowledge acquired from the games and the way to solving problems [32]. The reaction of a game and sensitivity of function are the third category and the fourth category, respectively, which include *attitudes*, *motivations*, and *communication method*. In the system of game scenes, according to categories 1 and 2of these learning outcomes, "Cognition and Motor Skills" are then used as the main framework for the development of a game. The design of game scenes is based on the learning outcomes. First, level (0) simulates the phenomena in natural environment. Then level (1) is connected to LMS with the game scenes. If there are other learning materials, they won't be stopped until all contents are input. The last level displays the whole lessons on the platform. Also, it gathers the data items in a game that can be evaluated and recorded. The final results are shown in Figure 8.

The game scenes are combined with AR main scene. The volume of our course content for LMS design scenarios is highly relevant. When the script is running game scenes, it will give priority to link the LMS input values in database length (n). Unity3Ds' assets are saved as global variable array patterns. Then, it is assigned as multiple scenes (n -1), and we apply the predefined avatar and the main task of NPC (Non-Player Character).

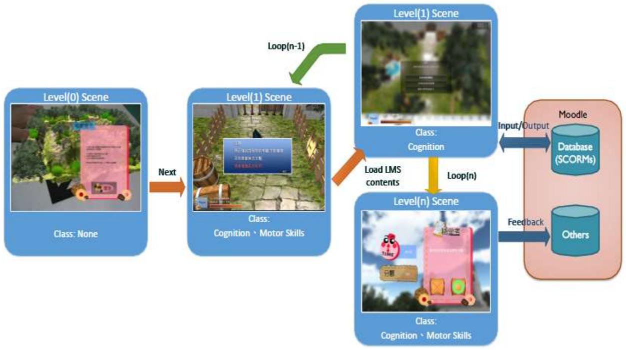

Figure 8. Game scenes flowchart.

3.2.2 Characters of AI

The predetermined logic is necessary to make the characters of AI (Artificial Intelligence). The most direct way is to write the program in accordance with the logic directly. But this method has heavy workload and is prone to making errors in the script. So, we can use a finite state machine (FSM) [33] to achieve behavioral logic, but this way is only suitable for a simple environment, as shown in Figure 9.

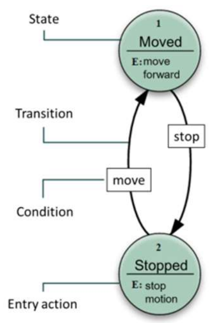

Figure 9. Basic character's motion in a finite state machine.

An FSM reflects the input data changed from the system at the present moment. It transfers to indicate state changes and makes sure that the input conditions must be met with metastasis. The action is active at a given moment. There are several types of actions, including "entry action: entering the state ","exit action: carrying out a state on exit ", "input action: depending on the current state and input conditions", and "transfer action: performing the specific transfer". In other words, the behavioral tree is a clear and easy module [34].

The game editor can be used to simplify the scene design and to perform efficient implementation of the results. The FSM is a simple and easy way to playing the role of AI behavioral logic [35]. When dealing with a large-scale environment, the FSM is more difficult to work out, maintain, and debug. In order to make an AI character's behavior to meet the needs of a game, we need to increase the number of states, i.e. a large number of manual conversion codes. So, the behavioral tree is suitable for an AI editor, which provides a wealth of process control for the designer. By defining a number of conditions and actions, we can achieve a complex AI game via a simple behavioral tree, as shown in Figure 10.

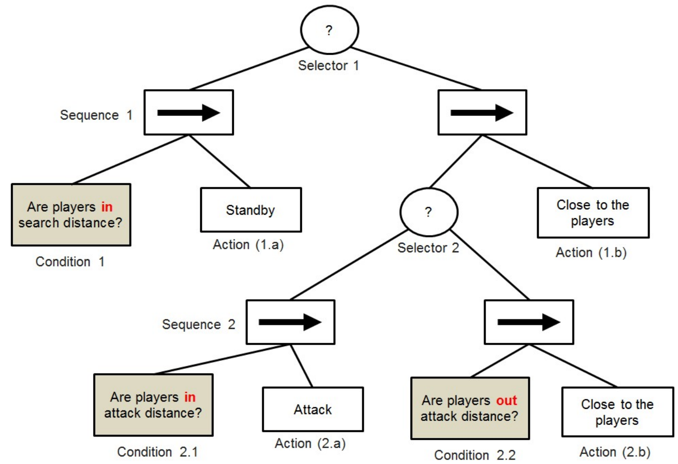

Figure 10. Behavioral tree in the game scene.

According to the interior design of the system, we use the AI character as described below, as shown in Figure 11.

Example:

The character's position in accordance with the player's avatar checks whether the attack action occurs or not. This AI logic has the following behaviors:

A. If the "search distance" from AI character to the player is less than a pre-set value (e.g., 10), then AI character moves forward; on the contrary, it stands motionless.

B. If the "attack distance" between AI character and the player is obtained, then AI character attacks the player; on the contrary, it continues to move forward.

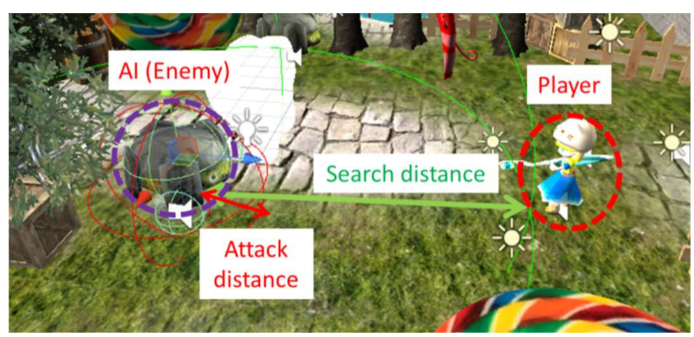

Figure 11. Implementation of the AI character in Unity3D.

3.2.3 Performance Assessment

The scenes of a serious game provide simulations, which can encourage students to learn more. Thus, it allows students to assess their learning results including cognition and concepts of science and technology. From the application of assessment to games, it has to connect the points with conjunctions. Both of them are strata, as shown in Figure 12. Since the assessment is developed based on teaching materials, students need to acquire correct knowledge and concepts. In the LMS, it can store students' records. The assessment can be categorized as *behavior* and *cognition*.

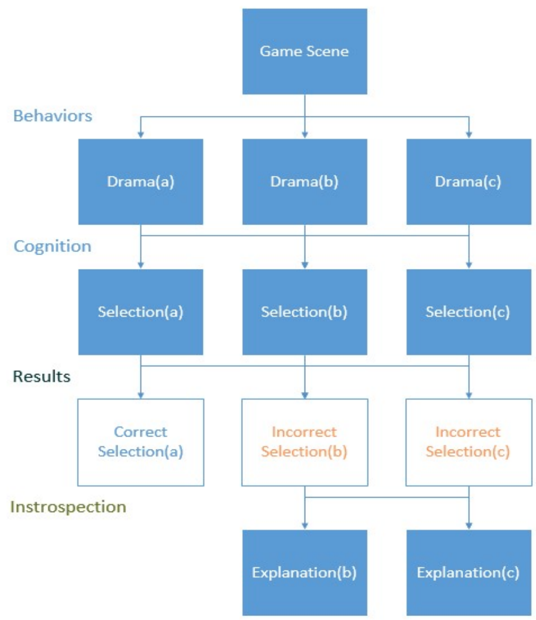

Figure 12. Performance assessment architecture.

The evaluation of behaviors utilizes the changes of scenes and the stuff connection to assess whether or not students can explore the scenes with correct behaviors by showing some hints to a path at the next level. Via independent thinking and the next phase in the search path, we can perform the student assessment which is correct, and complete the execution context of correct behaviors. Assessment of cognition allows students to clarify the concepts of science and technology by questioning the display in the game. In order to explore the path in each situation, it is possible to link student assessment of the concepts on science and technology. Students can achieve the learning assessment of the causal logic on scientific inquiry and courses. Students need to introspect by exploring the wrong situations so that they can be led to the correct path again. As students are in the game, it is inevitable to explore the incorrect situation. Whether or not the thinking or ideas are correct can produce another mechanism, or allow students to reflect deeper thinking. Then, it guides back to the correct path of exploration. If not, this platform will feedback to LMS as a record shown in Figure 13.

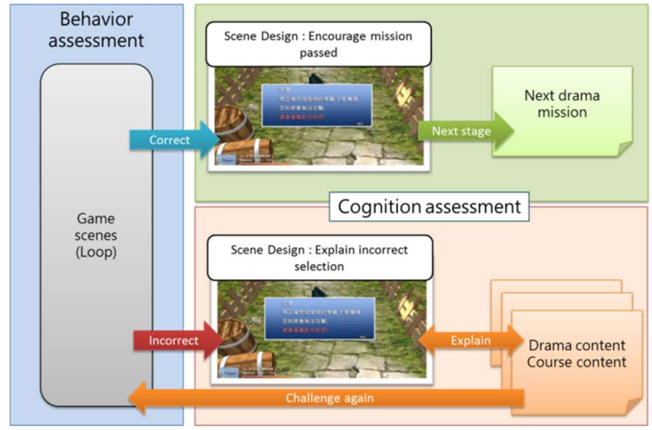

Figure 13. Performance assessment.

3.3 Implementation

First, the courses are built in the Moodle platform with digital learning materials based on SCORM standard. Then, the Unity3D scenes directly load the LMS, as shown in Figure 14. When the teacher updates the LMS platform, the Unity3D game scene can access to the course content in the client system. After starting the game, it loads the scene with a pre-test. The third unit entitled "invisible air" in science and technology is taken for pre-test contents [36]. The game story is imported to the scene with domain knowledge. But in the partial AR scene, it allows students to experience their own virtual space and guided instructions. Then, it gives players an avatar on the scene with a major mission, and is completed within the game story. Finally, after the completion of tests, it presents the resulting scene with detailed records including student's playing time, scores, results, and the number of correct questions. Then, it returns these data values to the database, as shown in Figure 15.

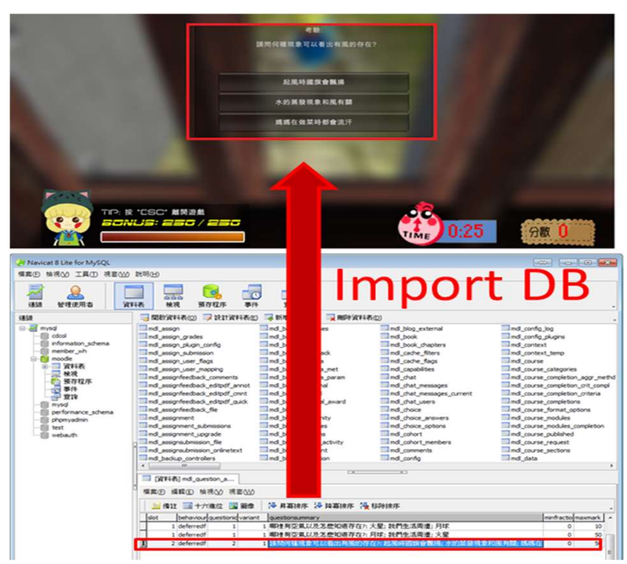

Figure 14. Database imported from LMS platform.

In summary, the player completes the main task of a scene, and displays the playing time with the player's score in the final outcome. Players will be able to view their own span of time spent, and obtain their scores. It displays the player's pre-test scores, (e.g. in 10 questions, answer 6 questions correctly, then obtain a score of 69) and post-test scores, (e.g. in 10 questions, answer 8 questions correctly, then obtain a score of 95). However, according to the course contents, the subject has different degrees of difficulty because the scores are not the same.

Figure 15. Resulting scene displaying all data values in the system.

Therefore, the main purpose of this system is to present the observation and analysis of the tested player's ability. It makes players feel like a role-playing game, which has different characters as the game is not subject to being changed. In order to provide these independent gaming scripts for players to choose, they seem to be like the story, allowing them to feel like the real world to experience different games.

4. Experimental Results

In this Section, we detail the game-based e-Learning system with AR. Take the third Unit for example, entitled "invisible air" in the subject on science and technology. It can be divided into three methods of assessment, namely, game-based e-Learning, normal e-Learning, and traditional learning. The assessment of this study has two stages. First stage is the construction of courses and a pre-test, which selects the contents of courses as pre-test questions. Second stage is to lead three teaching groups and process a post-test with the same questions. Finally, students can give a feedback to the system. It's assumed that teachers can trigger students to learn more by using a game-based e-Learning system, as shown in Figure 16. Three classes are chosen. In each class, we chose 29 students who were graded as top 29 of all students in the class. The total number of students is 87 and they are grouped as testing samples. Game-Based e-Leaning was conducted in Experimental Group 1(EG1). Normal e-Learning was conducted in Experimental Group 2(EG2) and all the outcomes were compared with the traditional learning method (i.e. Control Group, CG).

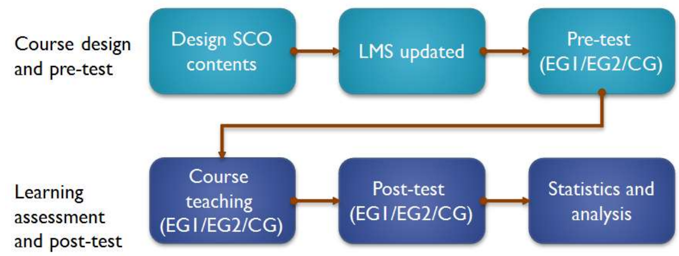

Figure 16. Performance assessment.

4.1 Experimental Assessment Design

In this Sub-section, we discuss the learning courses which present the benefits from a game-based e-Learning system. The experimental assessment design and teaching materials design in groups EG1/EG2/CG are also described.

Effectiveness of a game-based e-Learning system:

The main test in EG1 aims to get the learning results on the "invisible air" course.

a. Pre-test / post-test

First, students learn to take a pre-test. Then, after using the game-based e-Learning system, they are asked to take a post-test. Using the previous EG2/CG pre-test and post-test intends to compare the effectiveness of student's learning performance.

b. AR scene and serious game scenes

In the AR scene, it is first led by the teacher's observation and analysis of the students' performance regarding instructions and tips on the target scene. Then, the teacher teaches students how to operate with AR scenes. However, in the serious game scene, it is completely operated by the students themselves. The game story leads students to exploring their own courses. Finally, the teacher can rely on the learning data items on the LMS server to view student's learning performance.

4.1.1 Experimental Time and Student Attendees

EG1, EG2, and CG denote three experimental groups. They taught two main lessons in 80 minutes. However, EG1 group needs extra 10 minutes for students to answer the satisfaction survey on a game-based e-Learning system. The attendees are all third grade students in the elementary school. Their age is about 9 years old. They have not studied the Unit entitled "invisible air" before.

4.1.2 Experimental Procedures

1. Grouping subjects

All attendees are at the same grade. However, the number of attendees is different in each class. The class with the least number of students, 29, was selected as our experimental target. Three classes were selected. Randomly sampling students were grouped together.

2. Learning processes and contents

The learning processes are divided into EG1, EG2, and CG. All attendees choose the textbook in Kang Hsuan version as course contents[36]. The contents contain Unit 3 in the third-grade student's subject on science and technology, including “Features of the air”, ”The air flow forming wind”, and “Invisible air” as a scope of learning materials.

a. EG1/EG2 learning outlines: EG1 and EG2 choose the power point slides and video courses as a learning textbook on the LMS platform. In addition, the AR scene and serious game are rendered as learning materials in EG1.

b. CG learning outlines: In the traditional paper-based learning, the textbook is also in Kang Hsuan version. Then, the students' learning can be performed with their supplementary materials, such as anemometers, balloons, and syringe.

3. Assessment of learning

The scores of a pre-test and a pro-test can be used to evaluate the effectiveness of students' learning performances. However, the insufficient cognition and opinion scan be evaluated and considered by their teachers through the time period when playing the games, scene scores, avatar status, and so on in EG1.

4.2 Assessment Results

In the pre-test, EG1 got the lowest score, 27. EG2 got the best score, 92. And the average score is above 58 for each sample. In the post-test, EG2 got the lowest score, 30. All groups set the best score as 100. And the average score is above 69, as shown in Table 2.

Table 2. Descriptive statistics.

	Group	n	Min	Max	AV	SD
Re-test	EG1	29	27	91	59.7	16.9
	EG2	29	29	92	58.9	20.5
	CG	29	29	91	63.6	18.6
Post-test	EG1	29	45	100	82.1	13.5
	EG2	29	30	100	69.3	20.7
	CG	29	43	100	72.9	15.9

Note : 29 students chosen as a group(EG/CG), a total of 87 students.

Because there are only 29 attendees in each group (n<30), the volume of samples is not so huge. The pre-test and the post-test do not have normal distribution of scores, and the pre-test and the post-test comply with each other. So, we apply ANOVA (Analysis of Variance) for the research tool. The number of samples in each group is set the same in order to compare the performance of each group between high score and low score. When the variation of ANOVA reaches significance level at 0.05, the test will be performed in the Post Hoc LSD (Fisher least significant difference Test).

Before interference, no significant differences are shown in the performance of any two groups ($F(2,84) = .525$, $p = .593$). After the interference, three significant differences between any two groups are ($F(2,84) = 4.314$, $p < .05$), LSD test results for the EG1 > EG2and CG; and 2 scores in two experimental groups and the control group have significant difference. It has shown that the experimental group, EG1, is more effective than other two groups, EG2 and CG, as shown in Table 3.

Table 3. Descriptive ANOVA statistics.

	Group	n	AV	SD	F	Post Hoc Comparisons
Before	(1)EG1	29	59.79	16.914	0.525	-
	(2)EG2	29	58.90	20.575		
	(3)CG	29	63.66	18.695		
After	(1)EG1	29	82.10	13.566	4.314**	(1)>(2) and(3)
	(2)EG2	29	69.38	20.746		
	(3)CG	29	72.97	15.927		

*$F(2,84)=4.314, p<.05$(after)
**$F(2,84) = .525$, $p = .593$(before)

In the game-based e-Learning system, the feedbacks have shown that in EG1, 28 out of 29 students thought the system helped them know better about the Unit entitled “invisible air” and found it more interesting. 22 students agreed that the system improved the quality of learning. 24 students found that the interface was user-friendly. 18 students reckoned that the game helped them broaden the extent of courses. But 3 students thought that the user interface was too complicated to be operated easily.

4.3 Functional Comparison

In this Sub-section, three learning methods are compared with each other. First, for the comparison between the e-Learning method and the traditional learning method, the latter one is limited in time and space. Only the game-based e-Learning has situated learning in the game scenes, and also has high degree of interactivity. Finally, we easily find that the game-based e-Learning can have a large number of learning experiences.

Table 4. Descriptive learning methods.

Items \ *Methods*	*Game-Based e-Learning*	*Normal e-Learning*	*Traditional Learning*
Environment	Real world & Virtual world	Cyberspace	Real World
Environmental Limitations	No	No	Time and Space
Situated Learning	Yes	No	No
Interactivity	High	Low	Low
Learning Records	Yes	Yes	No
Course Transmission Media	Network	Network	Manually

5. Conclusions

According to the experimental results in Section 4, thee-Learning system is actually much more effective than the traditional learning system. It has presented the following contributions:

(1) By analyzing the experimental results from EG1, EG2, and CG attendees with the average values including 82.10, 69.38, 72.97, respectively, the game-based e-Learning system is much more efficient for students to acquire some knowledge than the traditional learning system.

(2) The students in EG1 can automatically participate in the processes of teaching-learning and know why the questions are asked in the tests. It reflects the fact that people can perform learning by playing as shown in Figure 15.

(3) Compared with LMS, the game-based e-Learning system can even boost the efficacy of learning the subject on science and technology as shown in Figure 14.

However, in the future, the game-based e-Learning system needs to allow students to play games and to acquire more knowledge at the same time so that they will be able to consider additional cognition.

Acknowledgments

The authors are very grateful to the anonymous reviewers for their constructive comments which have improved the quality of this paper. Also, this work was supported by the Ministry of Science and Technology, Taiwan, under grant MOST 107-2221-E-845-001-MY3.

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